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Bulk Superconductivity at 2.6 K in Undoped $RbFe_2As_2$

Z. Bukowski[a], S. Weyeneth[b], R. Puzniak[c], J. Karpinski[a], and B. Batlogg[a]

[a]*Laboratory for Solid State Physics, ETH Zurich, CH-8093 Zurich, Switzerland*
[b]*Physik-Institut der Universität Zürich, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland*
[c]*Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02-668 Warsaw, Poland*

Abstract

The iron arsenide $RbFe_2As_2$ with the $ThCr_2Si_2$-type structure is found to be a bulk superconductor with $T_c = 2.6$ K. The onset of diamagnetism was used to estimate the upper critical field $H_{c2}(T)$, resulting in $\mu_0 dH_{c2}/dT \simeq -1.4$ T/K and an extrapolated $\mu_0 H_{c2}(0) \simeq 2.5$ T. As a new representative of iron pnictide superconductors, superconducting $RbFe_2As_2$ contrasts with $BaFe_2As_2$, where the Fermi level is higher and a magnetic instability is observed. Thus, the solid solution series $(Rb,Ba)Fe_2As_2$ is a promising system to study the cross-over from superconductivity to magnetism.

Key words: $RbFe_2As_2$, iron pnictides, upper critical field, transition temperature, superconductivity
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1. Introduction

The family of iron oxyarsenide LnFeAsO$_{1-x}$F$_y$ (Ln = Lanthanide element) exhibits superconductivity with a maximum T_c up to 56 K [1, 2]. Additionally, the iron-arsenide compounds AFe_2As_2 (A = alkaline earth element), crystallizing in the $ThCr_2Si_2$-type structure, are known to become superconducting with T_c's up to 38 K upon alkali metal substitution for the A element [3, 4, 5], or partial transition metal substitution for Fe [6]. In contrast to undoped $BaFe_2As_2$ with a magnetic ground state, superconductivity with relatively low T_c's was reported in the undoped alkali metal iron-arsenides KFe_2As_2 (T_c = 3.8 K) and $CsFe_2As_2$ (T_c = 2.6 K) [4]. Interestingly, $RbFe_2As_2$ is known to exist as well [7], although its physical properties have not been reported so far. Here we report on the superconductivity in undoped alkali metal iron arsenide $RbFe_2As_2$.

2. Experimental Details

Polycrystalline samples of $RbFe_2As_2$ were synthesized in two steps. First, RbAs and Fe_2As were prepared from pure elements in evacuated and sealed silica tubes. Then, appropriate amounts of RbAs and Fe_2As were mixed, pressed into pellets and annealed at 650 °C for several days in evacuated and sealed silica ampoules. Powder X-ray diffraction analysis revealed, that the synthesized $RbFe_2As_2$ is single phase material with lattice parameters a = 3.863 Å and c = 14.447 Å. Magnetization data have been recorded using a Quantum Design MPMS XL SQUID Magnetometer, equipped with a Reciprocating Sample Option.

Email address: bukowski@phys.ethz.ch (Z. Bukowski)

3. Results and Discussion

A polycrystalline sample of $RbFe_2As_2$ was studied for its low temperature magnetic properties. In Fig. 1 the magnetic moment in the field-cooled state (FC) and in the zero-field cooled state (ZFC) in a magnetic field of 1 mT are shown. The data are indicative of bulk superconductivity. The distinct onset of diamagnetism due to superconductivity is observed at $T_c \simeq 2.6$ K. Due to the limited temperature range of the equipment, the full development of the Meissner state could not be recorded. Nevertheless, the observed ZFC diamagnetic response mirrors bulk superconductivity and is consistent with the sample dimensions. The pronounced difference between the ZFC and FC curves stemms from remarkable flux-pinning in the sample, suggesting rather high critical current density.

The upper critical field H_{c2} was estimated from magnetiza-

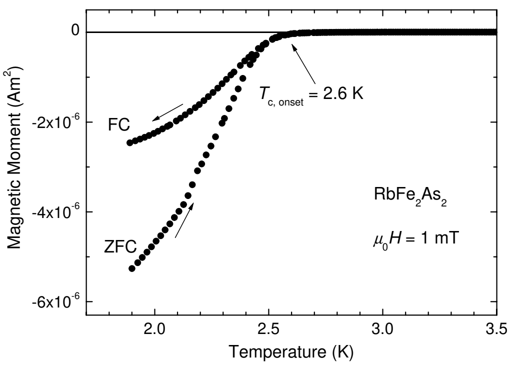

Figure 1: Temperature dependence of the magnetic moment of a $RbFe_2As_2$ polycrystalline sample, measured in a magnetic field of 1 mT. Superconductivity sets in at $T_c \simeq 2.6$ K.

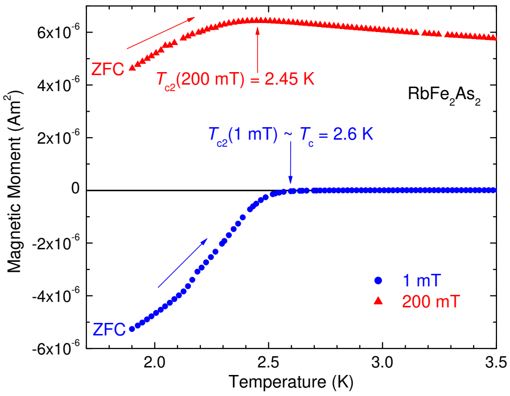

Figure 2: Representative data of the magnetic moment used for the determination of $H_{c2}(T)$, here for 1 mT and 200 mT, measured in the ZFC mode. A relative shift of the onset of superconductivity of 0.15 K is observed. An additional magnetic moment in the normal state in the 200 mT measurement, originates from a major normal state magnetic contribution.

tion measurements performed at various magnetic fields in the mixed state. In Fig. 2, two representative measurements of the magnetic moment versus temperature are displayed for $\mu_0 H = 1$ mT and for $\mu_0 H = 200$ mT. We defined the upper critical field H_{c2} as the magnetic field H, where $T_{c2}(H)$ is located. An obvious shift of the onset of superconductivity of 0.15 K is observed between the respective fields. In addition to the diamagnetic signal due to superconductivity, a distinct paramagnetic response develops due to the normal state magnetic contribution, rendering an accurate determination of $H_{c2}(T)$ rather difficult. Nevertheless, since a clear downward curvature is observed due to the onset of superconducting diamagnetism, the trend of $H_{c2}(T)$ can be followed down to 2 K. Figure 3 shows a summary of the results up to a field of 0.8 T, anticipating a linear slope close to T_c of $\mu_0 dH_{c2}/dT \simeq -1.4$ T/K. Assuming a simple WHH temperature dependence [8], which is known not to be applicable for the Fe pnictide superconductors with much higher transition temperatures, one would extrapolate $\mu_0 H_{c2}(0) \simeq 2.5$ T, in comparision to the lower critical field $\mu_0 H_{c1}(0) \simeq 4$ mT, as we estimated from field dependent initial magnetization curves, and the thermodynamic critical field $\mu_0 H_c(0) \simeq 100$ mT. Superconductivity is, obviously, of type II. The solid solution (Rb,Ba)Fe_2As_2 offers a particularly simple example where the interrelation between magnetic and superconducting ground states in the Fe pnictides can be studied through the controlled shift of the Fermi level. $BaFe_2As_2$ shows antiferromagnetic ordering competing with superconducting state. Appearently, doping of $RbFe_2As_2$ with Ba leads to a natural picture of enhancing T_c in the superconducting state, as the charge carrier concentration is varied. The appearence of superconductivity in $RbFe_2As_2$ opens up the window for a new interpretation of the occurence of superconducting state in (Rb,Ba)Fe_2As_2 [5, 9].

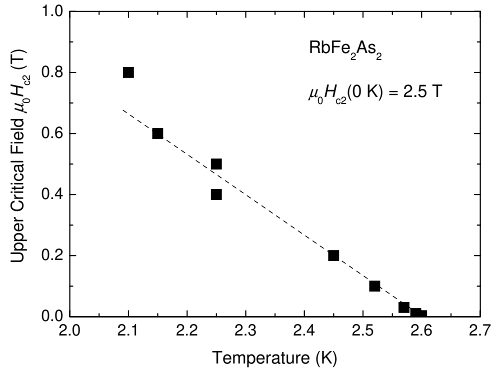

Figure 3: Temperature dependence of H_{c2} for $RbFe_2As_2$. The estimate of $\mu_0 H_{c2}(0) \simeq 2.5$ T is made using the WHH-approach.

4. Conclusions

Superconductivity is observed in undoped $RbFe_2As_2$ with a $T_c \simeq 2.6$ K. In this sense, it is useful to consider $RbFe_2As_2$ as a superconductor, located at the opposite end to the nonsuperconducting compound $BaFe_2As_2$ in the (Rb,Ba)Fe_2As_2 system. Therefore, superconductivity is enhanced by doping of an initially superconducting nonmagnetic parent compound. The upper critical field at zero temperature of $RbFe_2As_2$ is estimated to be $\mu_0 H_{c2}(0) \simeq 2.5$ T.

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